

# Creating a Mechanical Components Library for Circuit Design Software

Oleksandr Beznosyk, Oleksii Finogenov, Volodymyr Ladogubets, Oleksii Tchkalov

**Abstract** – In the paper the usage of equivalent circuits obtained from finite-element models to make a library of mechanical components is suggested. The experiments for a task with a complex geometry are conducted and the possibility of constructing an object model from its components is shown. The results of ANSYS calculations as well as ones obtained with the NetALLTED circuit design software are given.

**Keywords** – Simulation, ANSYS, NetALLTED, equivalent circuit.

## I. INTRODUCTION

The possibility to create an equivalent circuit model of a mechanical object is well-known for a long time [1] however it supposed manual description of the functionality of a source object as a number of dependent sources and other considerably non-linear electrical components whose forming is not unambiguous and hard for automatization.

In [2] the method to get automatically an equivalent circuit of a mechanical object presented as a finite-element model for further usage within the circuit design software has been described. In the paper presented the possibility to simulate complex geometrical constructions is considered as well as the ways to create library of base mechanical components as equivalent electrical circuits which can be used for building more complex constructions within CAD software.

## II. EXAMPLE DESCRIPTION

Let us consider the possibility to construct an object model (equivalent circuit) from models of its components by an example of a problem of finding eigenfrequencies and displacements of the construction presented on Fig. 1.

A frame consists of two straight-line cantilever beams  $AC$  and  $BC$  of the same length  $L$ . The beams fixed to each other at  $C$  point. Cross-sections of both beams are the same, look like a solid square of side  $a$ . A horizontal force  $F$  is applied at  $C$  point of the frame. In the issue of force application the frame deforms:  $AC$  beam is being mainly tensed while  $BC$  beam is being bended.

## III. ANSYS SIMULATION

To construct a mathematic model, ANSYS Multiphysics v.10.0 software developed by ANSYS Inc. [3] was used. ANSYS simulation took place under the following parameters:  $L = 1$  m,  $a = 0.05$  m; material properties: coefficient of elasticity  $E = 2 \cdot 10^{11}$  Pa, Poisson ratio  $\nu = 0.3$ , density  $\rho = 7.2 \cdot 10^3$  kg/m<sup>3</sup>.

For model discretization, ANSYS library's BEAM3 finite elements have been used. Every beam element has two nodes

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(left/right) with three degrees of freedom in each one: coordinates  $x$ ,  $y$  in a plane of motion and a corresponding beam cross-section's turn angle  $u$ . All the elements have the identical length of 0.2 m, thus the design model consists of 10 beam elements and 11 nodes.

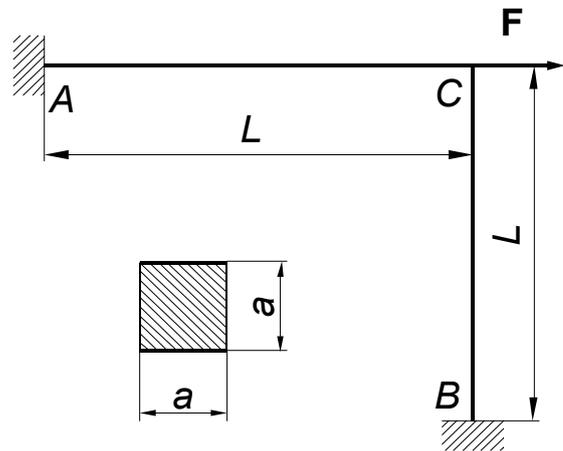


Fig. 1 Construction scheme.

Fig. 2 represents ANSYS simulation of the static deformation of the frame under  $F$  force. The horizontal ( $U_x$ ) displacements obtained for static loading of the frame by force  $F = 100$  N and the eigenfrequencies obtained during modal analysis of the frame are shown in Table 1.

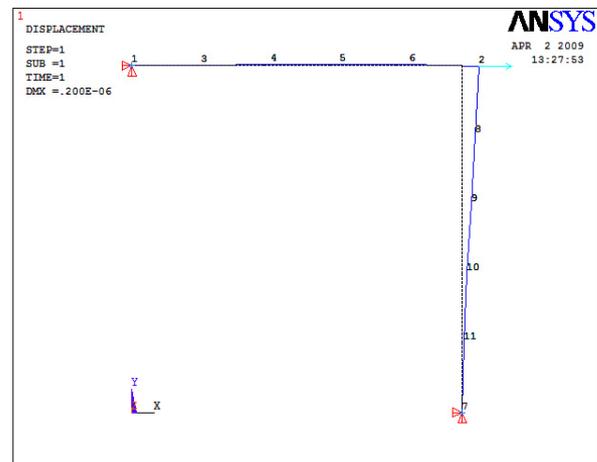


Fig. 2 ANSYS static deformation simulation.

TABLE 1  
SIMULATION RESULTS

Nod e	$U_x$ , mm	Nod e	$U_x$ , mm	Nod e	$U_x$ , mm	Mode	Freq., Hz
1	0	5	0.11981	9	0.10781	1	185.95
2	0.19969	6	0.15975	10	0.055899	2	268.20
3	0.039938	7	0	11	0.15971	3	596.25
4	0.079875	8	0.15973			4	718.86

#### IV. EQUIVALENT CIRCUIT SIMULATION

According to the electro-mechanical analogies, electrical circuit's node voltages are equal to the velocities of the respective mechanical model nodes. Numerical value of the displacement for the specific node can be obtained by adding an integrator to the circuit which consists of a current source controlled by the respective node voltage and a unit capacitance inserted in parallel to it. In NetALLTED language [4] the integrator description looks like:

```
J2(0,30)=FL(1/UC59);
C100(30,0) = 1;
```

In this case, the input influence is being simulated by means of the step-by-step lifting up a current source to the value equal numerically to the force  $F$ :

```
J1(0,13)=FTAB(0,0,0.5,100,1,100);
```

Thus, the simulation of a static mechanical tension is equal to the transient analysis execution while steady state corresponds to the static tension equilibrium equation. The simulation results for the equivalent circuit obtained for this frame as described in [2] coincide with those got by ANSYS and also match the analytical calculations.

#### V. BUILDING EQUIVALENT CIRCUIT FROM COMPONENTS

And now let us make the following thought experiment. Break the direct connection between beams at  $C$  point (Fig. 3) and maintain the interaction by applying appropriate kinematic and force boundary conditions. The boundary conditions can be reduced to following laws:

1. The velocity of  $C$  point is the same for both beams; the angular velocity of  $C$  cross-section is the same for both beams (kinematic identity).
2. To any action (force or moment) on a particular beam there is an opposite reaction applied to other beam (Newton's third law).

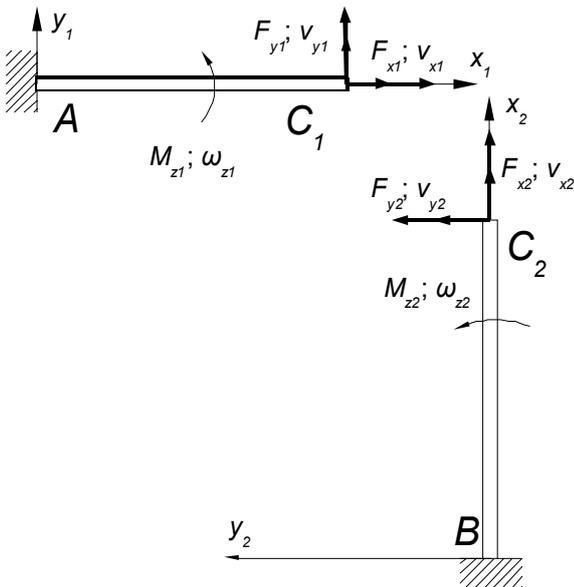


Fig. 3 Interaction between two beams.

By taking into account local coordinate axis directions, these conditions can be formalized in following equations:

$V_{x1} = -V_{y2}$ ;  $V_{y1} = V_{x2}$ ;  $F_{x1} = F_{y2}$ ;  $F_{y1} = -F_{x2}$ ;  $M_{z1} = -M_{z2}$ ;  $\omega_{z1} = \omega_{z2}$ , where  $V$  is a velocity component;  $F$  is a force component;  $\omega$  is the angular velocity of the  $C$  cross-section;  $M$  is the bending moment applied to the  $C$  cross-section.

So, the construction in question could be presented as a combination of two straight-line beams.

After getting from ANSYS an equivalent circuit of the straight-line beam, it can be used as a model in the circuit design software. The boundary conditions could be presented as a number of dependent current and voltage sources (Fig. 4).

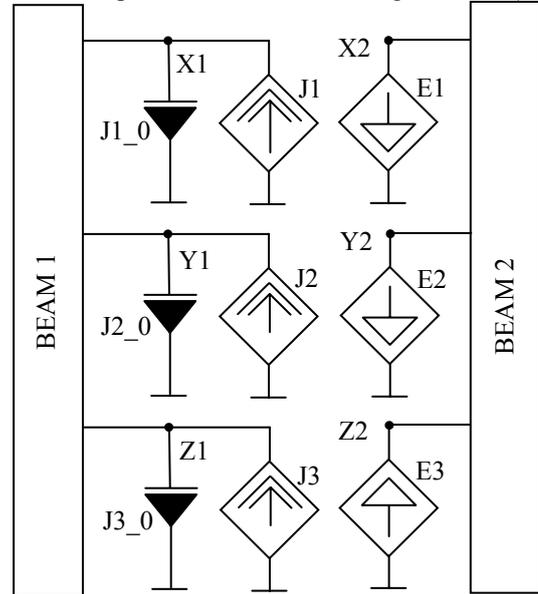


Fig. 4 Equivalent presentation of interaction between two beams.

These sources establish connections between couples of nodes according to the component equations the NetALLTED description of which generally looks like:

```
# Fx1=Fy2
# Vx1=-Vy2
J1(BASE,X1)=FL(1/IE2);
E2(BASE,Y2)=FL(1/UJ1_0); #fix node potential
J1_0(X1,BASE)=0;
# Fy1=-Fx2
# Vy1=Vx2
J2(BASE,Y1)=FL(1/IE1);
E1(BASE,X2)=FL(1/UJ2_0); #fix node potential
J2_0(Y1,BASE)=0;
# Mz1=-Mz2
# ωz1=ωz2
J3(BASE,Z1)=FL(1/IE3);
E3(Z2,BASE)=FL(1/UJ3_0); #fix node potential
J3_0(Z1,BASE)=0;
```

The dependences between the sources are linear and describing by the FL function [5], the first parameter of which is a coefficient depending on the angle between two beams. BEAM 1 and BEAM 2 is in fact the same model representing the straight beam (see [2] for its equivalent circuit design).

In whole, NetALLTED circuit description looks like:

```
J5(0,X1)=FTAB(0,0,0.5,100,1,100);
#for transient analysis
#J5(0,X1)=100; #for frequency analysis
J6(0,30)=FL(1/UJ5); #integrator to define
C100(30,0)=1; #displacement
Q1(0,X1,Y1,Z1)=BEAM; Q2(0,X2,Y2,Z2)=BEAM;
J1(0,X1)=FL(1/IE2); E2(0,Y2)=FL(1/UJ1_0);
J2(0,Y1)=FL(1/IE1); E1(0,X2)=FL(1/UJ2_0);
J3(0,Z1)=FL(1/IE3); E3(Z2,0)=FL(1/UJ3_0);
```

```

J1_0(X1,0)=0; J2_0(Y1,0)=0; J3_0(Z1,0)=0;
Model BEAM(0,13,14,15);
C1(4,1)=-6.00000000E-01;
C2(5,2)=-4.40349943E-01;
C3(6,2)=2.19105943E-02;
C4(5,3)=-2.19105943E-02;
C5(6,3)=1.05357943E-03;
C6(7,4)=-6.00000000E-01;
C7(6,5)=-2.08166817E-17;
C8(8,5)=-4.40349943E-01;
C9(9,5)=2.19105943E-02;
C10(8,6)=-2.19105943E-02;
C11(9,6)=1.05357943E-03;
C12(10,7)=-6.00000000E-01;
C13(9,8)=4.16333634E-17;
C14(11,8)=-4.40349943E-01;
C15(12,8)=2.19105943E-02;
C16(11,9)=-2.19105943E-02;
C17(12,9)=1.05357943E-03;
C18(13,10)=-6.00000000E-01;
C19(14,11)=-4.40349943E-01;
C20(15,11)=2.19105943E-02;
C21(14,12)=-2.19105943E-02;
C22(15,12)=1.05357943E-03;
C23(15,14)=3.80894057E-02;
C24(1,0)=3.00000000E+00;
C25(2,0)=3.13773946E+00;
C26(3,0)=2.37999360E-02;
C27(4,0)=3.60000000E+00;
C28(5,0)=3.60000000E+00;
C29(6,0)=8.35762286E-04;
C30(7,0)=3.60000000E+00;
C31(8,0)=3.60000000E+00;
C32(9,0)=8.35762286E-04;
C33(10,0)=3.60000000E+00;
C34(11,0)=3.60000000E+00;
C35(12,0)=8.35762286E-04;
C36(13,0)=1.80000000E+00;
C37(14,0)=1.78382119E+00;
C38(15,0)=-5.95821189E-02;
L1(4,1)=4.00000000E-10;
L2(5,2)=6.39795266E-09;
L3(6,2)=-6.39795266E-08;
L4(5,3)=6.39795266E-08;
L5(6,3)=-9.59692898E-07;
L6(7,4)=4.00000000E-10;
L7(6,5)=8.94784853E+07;
L8(8,5)=6.39795266E-09;
L9(9,5)=-6.39795266E-08;
L10(8,6)=6.39795266E-08;
L11(9,6)=-9.59692898E-07;
L12(10,7)=4.00000000E-10;
L13(9,8)=-5.96523236E+07;
L14(11,8)=6.39795266E-09;
L15(12,8)=-6.39795266E-08;
L16(11,9)=6.39795266E-08;
L17(12,9)=-9.59692898E-07;
L18(13,10)=4.00000000E-10;
L19(14,11)=6.39795266E-09;
L20(15,11)=-6.39795266E-08;
L21(14,12)=6.39795266E-08;
L22(15,12)=-9.59692898E-07;
L23(15,14)=6.39795266E-08;
L24(1,0)=4.00000000E-10;
L25(2,0)=5.81632060E-09;
L26(3,0)=-9.59692898E-08;
L27(5,0)=1.31316330E+08;
L28(6,0)=1.59948816E-07;
L29(7,0)=2.12832869E+06;
L30(8,0)=2.98027167E+07;
L31(9,0)=1.59948816E-07;
L32(10,0)=-9.76128931E+07;
L33(11,0)=1.01337477E+09;
L34(12,0)=1.59948816E-07;
L35(14,0)=-3.19897633E-08;
L36(15,0)=3.19897633E-07;

```

## VI. SIMULATION RESULTS

The numerical results of the NetALLTED simulation of the object in question built from the components fully coincide with those obtained for the single object. On Figs. 6 and 7 the NetALLTED frequency and transient analysis results are shown. The values of four frequencies (Fig. 6) are the same as those presented in Table 1 while the maximal displacement of the construction (Fig. 7) is equal to the ANSYS node 2 one.

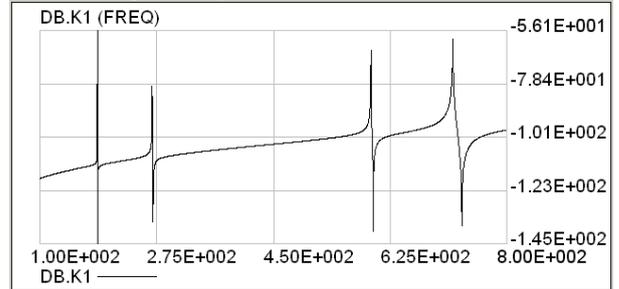


Fig. 6 NetALLTED frequency analysis.

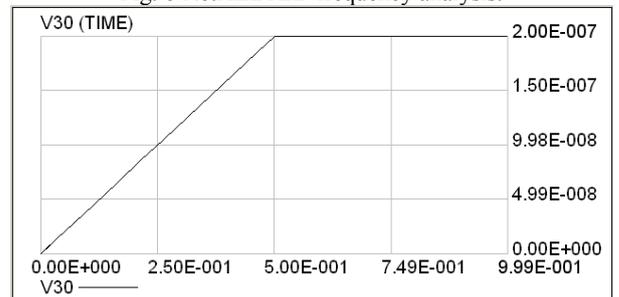


Fig. 7 NetALLTED transient analysis.

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## VII. CONCLUSION

The results presented confirm the possibility to create a library of base mechanical component models as equivalent linear RLC circuits for using within the circuit design software instead of complex non-linear functions the process of forming which is hard to be formalized. The development of such library will allow using its component models to create complex mechanical objects as equivalent circuits without a necessity to build such object in whole by any finite-element-based software. Obviously that in a case of large finite-element models it is required to reduce and optimize equivalent circuits prior to including such models into a CAD software library. This is a subject of the following investigations.